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CONCRETE CASK TEST PROGRAM - PRELIMINARY REPORT

Report No 83-466-K

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ABSTRACT

This report outlines the scope of the proposed concrete cask test program, and presents an analysis of the test facilities, equipment and instrumentation required.

The proposed test program should include drop and thermal tests (with a water immersion test to be implemented in the future), as required by the IAEA (International Atomic Energy Agency) regulations, to demonstrate the ability of the concrete cask to withstand accident conditions in transport. In addition to the IAEA requirements, the program should also include a decay heat test to ensure that the concrete cask will be capable of withstanding and dissipating the decay heat of the irradiated fuel under storage conditions. An investigation of the required test facilities, equipment and instrumentation indicates that all the above-mentioned tests are technically feasible if half-scale models are used for testing. The general scaling laws, however, are not entirely applicable to concrete casks due to certain material characteristics unique to concrete. Some approximations will, therefore, be unavoidable if scale model testing techniques are used.

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CONCRETE CASK TEST PROGRAM - PRELIMINARY REPORT

1.0 INTRODUCTION

Commencing January 1983, Ontario Hydro undertook a two-year development program to investigate the possible use of concrete casks as a means of storing, transporting and disposing of irradiated fuel. As a part of this overall development program/1/, the Civil Research Department has assumed the responsibilities of evaluating, by way of a test program, the structural performance of a concrete cask currently being designed by the Civil Design Department. In setting the groundwork for this test program, an initial investigation has been completed which includes a literature survey of similar test programs and a preliminary analysis of test requirements with respect to facilities, equipment and instrumentation. The findings of the initial investigation are presented in this report.

2.0 LITERATURE SURVEY

The literature survey was conducted to review the current development of concrete cask technology and the technical details of similar test programs. The intent of this survey is to become familiar with the techniques and experience developed from past research efforts and to utilize them in the test program now being planned by Civil Research.

2.1 Development of Concrete Cask Technology

In recognition of the fact that concrete is an effective and relatively inexpensive shielding material, researchers have given an increasing amount of attention to the development of concrete casks as a means of packaging nuclear wastes. In the past decade, countries that have been most active in designing and testing concrete casks include Canada, United States, Japan and Germany.

Developmental work in Canada began in 1974 with a test program by AECL (Atomic Energy of Canada Ltd)/2/ aimed at evaluating the performance of concrete casks in storing irradiated fuel. This initial test program yielded encouraging results and led to a subsequent test program/3/ in which the possibility of extending the function of the concrete casks from storing to transporting irradiated fuel was investigated. The results of the subsequent test program revealed that the cask wall would have difficulties passing the impact and puncture tests if made from normal reinforced concrete. It was apparent that the concrete cask wall had to be either strengthened or protected to attain the required impact and puncture resistance. This view is generally shared by other researchers involved in parallel research programs.

A number of methods of strengthening the concrete cask wall have been investigated. Studies/4/ have shown that the puncture resistance of concrete can be improved by simply providing more effective detailing of steel reinforcement. The use of certain metallic-based aggregates (eg, ilmenite, magnetite, hematite, etc) will also strengthen the concrete according to experience in both Canada/5/ and Germany/6/. In addition, testing of steel fibre reinforced, polymer-impregnated concrete casks in Japan/7/ has confirmed that steel fibre reinforcement improves the cask's resistance to impact and thermal loads, and that polymer impregnation increases its impermeability to water.

Other concepts of improving the structural strength of the cask wall involve the provision of an outer casing to protect the concrete wall. The casing may either be an outer steel liner which forms an integral part of the cask/6/ or a reusable concrete or steel 'overpack'/8,15/. The reusable 'overpack', which provides protection for the concrete cask during transportation, is retrieved just before the disposal of the waste package.

2.2 Similar Test Programs

In order to ensure that a designed cask is capable of withstanding accident conditions during transport, the IAEA (International Atomic Energy Agency) regulations/9/ require that the cask be subjected to a series of tests under specified guidelines. The test series includes drop, thermal and water immersion tests based on hypothetical accident conditions. The literature survey indicates that these IAEA tests have been performed on a wide variety of transport casks. Although the tests cited involve casks of different shapes and materials (many of which are steel-lead casks), a large number of similarities exist in the testing techniques used and in the general physical behaviour of casks observed under test loads.

The literature survey has revealed that scale model testing techniques have been commonly used to establish the basic behaviour and response of the casks. To facilitate scale model testing, general scaling laws have been theoretically derived using similitude analysis/10/. Testing of model casks with varying scale ratios has confirmed that physical parameters, such as stress, deformation, acceleration and time, can be correlated by these scaling relationships. The correlation, however, is generally consistent only with relatively large-scale ratios (over 1/4).

Drop tests typically involve dropping the test specimens at various angular positions and evaluating the damage sustained by the test specimens. Test results have shown that while the cask is likely to suffer the greatest damage from an oblique (corner) drop, the payload usually sustains the worst damage from an end drop due to the high deceleration. Oblique drop tests performed in the United States/11/ have further suggested that the damage sustained by the cask is also dependent on the relative position of the centre of gravity of the cask with respect to the point of impact. With the centre of gravity directly over the point of impact, the cask will likely suffer the maximum damage since the energy loss due to rotational motion of the cask after impact is minimized.

Unlike the drop tests, the thermal test does not have a clearly defined methodology. The IAEA regulations consider any thermal test method to be acceptable provided that the requirements of test parameters such as temperature, emissivity and exposure time are satisfied. The selection of a test method is generally reduced to a choice between the open-fire test and the furnace test. Comparative studies/12,13/ of the two test methods have indicated that the difference between the methods mainly lies in the repeatability of test results. In an open fire test, the temperature and emissivity depend greatly on the depth of flame, wind direction and wind velocity, and show poor repeatability. The furnace test produces more uniform temperature and emissivity, and has significantly better repeatability.

The behaviour of casks under thermal loads is mainly dependent on the thermal and mechanical properties of the cask materials and on the physical construction of the cask. In the case of concrete casks, stresses developed due to thermal gradient and differences in coefficients of thermal expansion between different materials can induce cracking.

In comparison to the drop and thermal tests, only a small number of water immersion tests have been reported. The water immer-

sion tests performed in Japan/14/ have shown that, with cylindrically shaped casks, the maximum longitudinal stresses occur along the inside corners while the maximum circumferential stresses are found along the inside circumference at the midpoint of the cylindrical wall.

3.0 CONCEPTUAL DESIGN OF CONCRETE CASK

The conceptual design of the concrete cask is based on geometric, shielding, thermal and mechanical requirements, and is primarily the responsibility of the Civil Design Department. While the design work is still continuing, preliminary details of the concrete cask have been established and are described as follows:

The prototype concrete cask consists of a main cask body, a concrete lid and an inner steel liner (see Figure 1, Appendix A). Given a cylindrical shape to provide better impact and pressure resistance, the concrete cask has overall dimensions of approximately 2.75 m x 2.41 m (diameter x height). The concrete cask wall is approximately 530 mm in thickness with two layers of steel reinforcements near each face. The inner steel liner is designed as a pressure vessel and serves as the immediate containment barrier for the fuel baskets. The steel liner is also cylindrically shaped so that fuel baskets of different configurations can be universally accommodated. After the placement of fuel baskets and cavity filling material around the fuel baskets, the top of the steel liner is welded shut (remotely by an automatic welding machine) completely sealing the payload chamber. Closure of the open end of the cask is achieved by a round, stepped concrete lid anchored to the main cask body. The anchorage system is recessed from the top surface of the cask, and consists of anchor bolts equally spaced along the lid circumference. The lid is sealed by a silicone gasket and grout.

As this concrete cask design does not include an outer protective casing, the structural strength of the concrete wall must provide sufficient resistance to impact and puncture. In addition, the wall must possess a high density for required radiation shielding, adequate thermal conductivity for effective heat dissipation and low permeability and high chemical stability for better durability. In search of an optimum concrete mix which will satisfy these performance requirements, Civil Research has engaged in an experimental program in which concrete mixes with varying cementing materials, admixtures and curing regimes are compared. In addition, fibre reinforcing and polymer impregnation are also being investigated for their technical benefits and practicality.

4.0 DESCRIPTION OF PROPOSED TEST PROGRAM

To meet the performance criteria specified in the IAEA regulations for the safe transport of radioactive materials, the following tests are necessary to demonstrate the cask's ability to withstand accident conditions in transport:

1. Mechanical Test

   The mechanical test requires that two drop tests be performed using the same test specimen in an order such that the test specimen will suffer the greatest damage on completion of the thermal test which follows.

   (a) Drop Test I

   The test specimen is dropped from a 9 m height onto an unyielding surface to suffer the maximum damage.

   (b) Drop Test II

   The test specimen is dropped from a 1 m height onto a vertical bar (15 cm ± 0.5 cm in diameter x 20 cm in length) rigidly mounted on the unyielding surface to suffer the maximum damage.

2. Thermal Test

   The same test specimen as previously used in the drop tests is subjected to a thermal radiation environment of 800°C for 30 min with an emissivity coefficient of 0.9.

3. Water Immersion Test

   The test specimen (different from that used for the mechanical and thermal tests) is immersed under a head of water of at least 15 m for a period of not less than eight hours.

On completion of the above tests, the test specimens, having sustained the damages, must still retain their shielding capability. The following acceptance criteria are suggested by the IAEA and AECB (Atomic Energy Control Board of Canada)/16/:

(a) The radiation level at one meter from the surface of the cask does not exceed 10 mSu/h (1 rem/h) (IAEA 228).

(b) The accumulated loss of radioactive materials in a period of one week is not more than $A_2 \times 10^{-3}$ (A_2 is an activity limit given in units of bequereles (or curies). (AECB sch IX, B(U) (3)).

In addition to the IAEA requirements, the test program should also include a decay heat test to demonstrate that the concrete cask is capable of withstanding and dissipating the thermal loading from irradiated fuel.

Decay Heat Test

The test specimen is to be subjected to the design decay heat load of 3 kW (for a full-scale model) internally, and to daily and seasonally varying ambient temperatures externally.

The acceptance criteria of the decay heat test are that the concrete temperature does not exceed a maximum value of 150°C and the shielding capability must be retained.

5.0 SCALING OF MODELS

Although prototype model testing provides the most accurate test results, it is often not practical due to the physical constraints of test equipment, handling difficulties and high cost. An analysis of the requirements of test equipment and facilities indicates that half scale models represent the best compromise between the accuracy of test results and the practicality of constructing and testing the model.

It must be pointed out, however, that the general scaling laws that work well for metal casks may not be entirely applicable to concrete casks. When cracking occurs in the concrete, the redistribution of forces that takes place to maintain equilibrium cannot be modelled adequately using simple scaling relationships. Errors, therefore, will be introduced if scale models are used. A theoretical analysis of the thermal behaviour of a representative concrete cask wall segment indicates that for a half scale model the differences in strains are approximately 10% before cracking but may increase to higher levels after cracking.

The scaling laws generally require that all elements of the model cask, including the steel reinforcements and concrete aggregates, be geometrically reduced by the same scale ratio. In the case of steel reinforcements, both the bar diameter and spacing should be scaled down so that the same steel to concrete area ratio is maintained. Scaling of concrete aggregates, however, is considerably more difficult since the mechanical and

thermal properties of the concrete must be maintained while the aggregate sizes are reduced. Experimental work may, therefore, be necessary to find a suitable concrete mix for the scale model satisfying this requirement.

6.0 CONSTRUCTION OF SCALE MODELS

With a scale ratio of 1/2, the weight of the model is reduced to a more manageable level (1/8 of that of the prototype) allowing the model to be constructed in the Civil Research Concrete Lab. The construction sequence may be summarized as follows:

1. Fabricate the steel liner from pipe and plate sections with the liner top initially detached.

2. Place the reinforcing steel for the main cask body and lid separately.

3. Install the embedded instruments (described in Sections 7 to 10 of this report) on the pre-formed reinforcing steel.

4. Construct the formwork for the main cask body and lid. The steel liner will serve as the inner formwork for the main cask body, but must first be supported. A tubular form of cardboard material may be used as the outer formwork.

5. Install the lid anchor bolts around the lid seat near the top of the main cask body.

6. Place concrete, in one continuous pour, for both the main cask body and lid.

7. After the concrete has hardened, strip the outer formwork and install the remaining (non-embedded) instruments.

8. For the drop-thermal test model, place weights inside the steel liner to simulate the gravity effect of the fuel baskets maintaining the centre of gravity at the homologous point. For the decay heat test, insert an electric heater (described in Section 10 of this report) into the annular space of the steel liner to simulate the effect of decay heat. A port should be provided through the cask wall for the power cables of the electric heater.

9. Seal the steel liner by welding its top on.

10. Provide a silicone seal around the lid seat and install the lid.

11. Finally, fix the lid by tightening the anchor bolts and grouting.

It is noted that certain details of the cask design need not be modelled exactly the same as the prototype provided that the deviations do not alter the general behaviour of the cask under the test loads considered. In the model used for the decay heat test, for instance, a simplified lid construction may be considered for greater ease of fabrication. A model cask using an unstepped circular lid with the original anchorage system will provide essentially the same structural system as that of the prototype under thermal loads. Also for easier accessibility of the electric heaters, the steel liner lid may be spot welded (rather than continuously welded) and the concrete lid may be sealed using low-strength grouting material (for easier removal).

7.0 DROP TESTS

Since IAEA regulations specify that the drop tests must be performed such that maximum damage is sustained, several test specimens will be required to determine which test sequence is most critical. The test specimens should be dropped in various angular positions (vertical, horizontal and oblique) and in different orders (Drop Test I and Drop Test II). In the oblique drop, the test specimen should be positioned such that its centre of gravity is directly above the point of impact to minimize the energy loss due to rotational movement of the specimen after impact.

The facility required for the drop tests consists mainly of an unyielding target and a lifting device. The unyielding target is normally constructed of a large block of reinforced concrete (approximately 3 m x 3 m x 3 m) cast into the ground and lined with a steel armor plate (approximately 100 mm in thickness) on the top. The lifting device may be either a mobile crane or a steel tower (approximately 12 m in height) equipped with hoisting apparatus. As the test specimen must be dropped vertically maintaining its angular position, a special release mechanism should be used to minimize the forces that may be imparted to the test specimen at release.

Two available sites have been considered for the drop tests, namely, the Civil Research test site at the Kipling Complex and the CRNL (Chalk River Nuclear Laboratories) test site of AECL in Chalk River, Ontario. While the Civil Research test site is presently without the required facility described above, the

CRNL test site has an existing concrete pad and steel tower complete with hoisting apparatus. Performing the drop tests at the CRNL test site, however, will require the test specimens to be transported to Chalk River after being constructed at the Kipling Complex.

The instrumentation necessary for the drop tests will serve the following functions.

1. To measure the deceleration of the test specimen during impact.

2. To measure the longitudinal and circumferential strains in the test specimen resulting from the impact.

The deceleration may be measured by triaxial accelerometers, and strains by embedded strain gauges. A recording device (oscillograph, FM tape recorder or transient recorder) will be necessary to monitor the dynamic response of the specimen. High speed motion pictures may also be used to verify the angular position of the test specimen at impact. It should be noted that since the same test specimens will be subjected to the thermal test following the drop tests, any embedded instruments required for the thermal test must be built into the same test specimen, preferably at locations with less likelihood of damage due to drop impact.

8.0 THERMAL TEST

Both the open-fire test and the furnace test have been evaluated for their technical advantages and disadvantages. Although the open-fire test best simulates the conditions of an actual accident fire, it almost never accurately reproduces the conditions specified in the IAEA test requirements. The furnace test, which provides repeatable results, better enables comparisons of the thermal resistance of different test specimens having sustained different amounts of damage from the preceding drop tests. The furnace test, however, requires warm-up time before the test temperature can be reached and cool-down time after the test (before the test specimen may be removed). This implies that the test specimen will be subjected to an exposure more severe than that specified in the test requirements, particularly for scale models for which exposure time will be scaled down.

An investigation of available thermal test facilities indicates that the following two options may be considered:

1. A furnace test using the furnace of ULC (Underwriters Laboratories of Canada) in Scarborough, Ontario.

2. An open-fire test using the fire pit of CRNL in Chalk River, Ontario.

The ULC furnace, with inside dimensions of 4.3 m x 3.7 m x 24 m (L x W x H), can reach the required test temperature of 800°C in less than 20 min. The furnace is equipped with 48 burners evenly distributed over the furnace floor and is fuelled by propane gas.

The CRNL fire pit, with overall dimensions of 4.9 m x 4.9 m, is constructed of refractory materials and enclosed on the four sides by a 3.0 m high windbreak. The fuel used is mainly kerosene with a small amount of gasoline added to help in igniting the fire.

An important consideration in the selection of a test facility is that the transportation of test specimens from the drop test site to the fire test site must be minimized to avoid unwarranted damages to the test specimen during transport. In view of this consideration, the following alternatives are suggested:

1. Perform the drop tests at Kipling Complex and the following thermal (furnace) test at ULC in Scarborough.

2. Perform both the drop tests and the following thermal (open-fire) test at CRNL in Chalk River.

The instrumentation required for the thermal test serves the function of establishing a temperature versus time relationship at various depths in the cask wall. The temperature measurement can be achieved by monitoring thermocouples (type K), embedded in the cask wall and placed around the cask, using a computer-based data acquisition system.

9.0 WATER IMMERSION TEST

The water immersion test can be performed by using the pressure water tank of AECL at WNRE (Whiteshell Nuclear Research Establishment) in Pinawa, Manitoba. The tank has inside dimensions of 1.5 m x 3.0 m (diameter x height) and will accommodate a half-scale model. The tank is capable of producing a maximum pressure of 10.3 MPa. (This is slightly higher than the design hydrostatic pressure of 10 MPa).

The required instrumentation includes embedded strain gauges to measure longitudinal and circumferential strains, and pressure transducers to measure internal and external pressures. Access for instrumentation cables is provided by a port through the wall of the pressure chamber. The instruments may again be monitored by a computer-based data acquisition system.

In place of an actual water immersion test, an analytical analysis using the finite element method may also be used to demonstrate the ability of the concrete cask to withstand hydrostatic pressure. The finite element model, however, must consider (a) the non-linear stress-strain relationship of materials, and (b) the permeability of concrete.

10.0 DECAY HEAT TEST

The decay heat test can be conducted entirely in the Civil Research Concrete Lab. Electric heaters placed into the annular space of the steel liner can be used to simulate the decay heat of irradiated fuel. The electric heaters consist of an annular vessel with heating elements placed around its circumference, and a controller for thermal output. The size of the electric heaters will be similar to that of scaled-down fuel baskets.

Heat transfer and accelerated weathering tests can be performed by placing the test specimen in the variable condition room which will accommodate a half-scale model. The variable condition room, with a temperature range of -18°C to 38°C and a humidity range of 25 to 75%, will simulate the varying ambient thermal environment. Freeze-thaw actions may be simulated by spraying water on the surface of the test specimen. Since the tests are performed indoors, however, the effects of snow, sunlight, wind etc, will not be simulated.

The instrumentation required for the decay heat test will serve the functions of (a) measuring the thermal gradient through the cask wall and (b) measuring the longitudinal and circumferential strains in the test specimen. Again, the thermocouples (Type T) for temperature measurements and embedded strain gauges for strain measurements can be monitored using a computer-based data acquisition system.

11.0 SCHEDULE AND COST ESTIMATE FOR THE PROPOSED TEST PROGRAM

The following is a tentative schedule of the proposed test program.

STARTING DATE OF TEST MODEL CONSTRUCTION	TEST
October 1983	Decay Heat Test
March 1984	Drop Tests and Thermal Test
Future	Water Immersion Test

A preliminary cost estimate based on the testing of a one-half scale model has also been prepared (see Appendix B). The actual scope and commencement dates of the test program will depend on the availability of funds.

12.0 CONCLUSIONS AND RECOMMENDATIONS

1. Outlined in this report is a proposed test program aimed at evaluating the structural performance of the concrete cask currently being developed by Ontario Hydro. The proposed test program includes drop, thermal, water immersion and decay heat tests.

2. A review of test requirements with respect to facilities, equipment and instrumentation indicates that the proposed test program is technically feasible.

3. For economic and practical reasons, half-scale models are most suitable for testing. An investigation of the applicability of general scaling laws shows that testing using half-scale models will provide reasonable approximations to the behaviour of the prototype cask.

4. It is recommended that Hydro first proceed with the decay heat test in October 1983, and the drop and thermal tests in March 1984. The water immersion test may be performed at a later date. The minimum required funding will be $25,000 for 1983 and $172,000 for 1984 (based on the assumption that the drop and thermal tests are performed at CRNL).

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APPENDIX A

SECTIONAL VIEW OF CONCRETE CASK

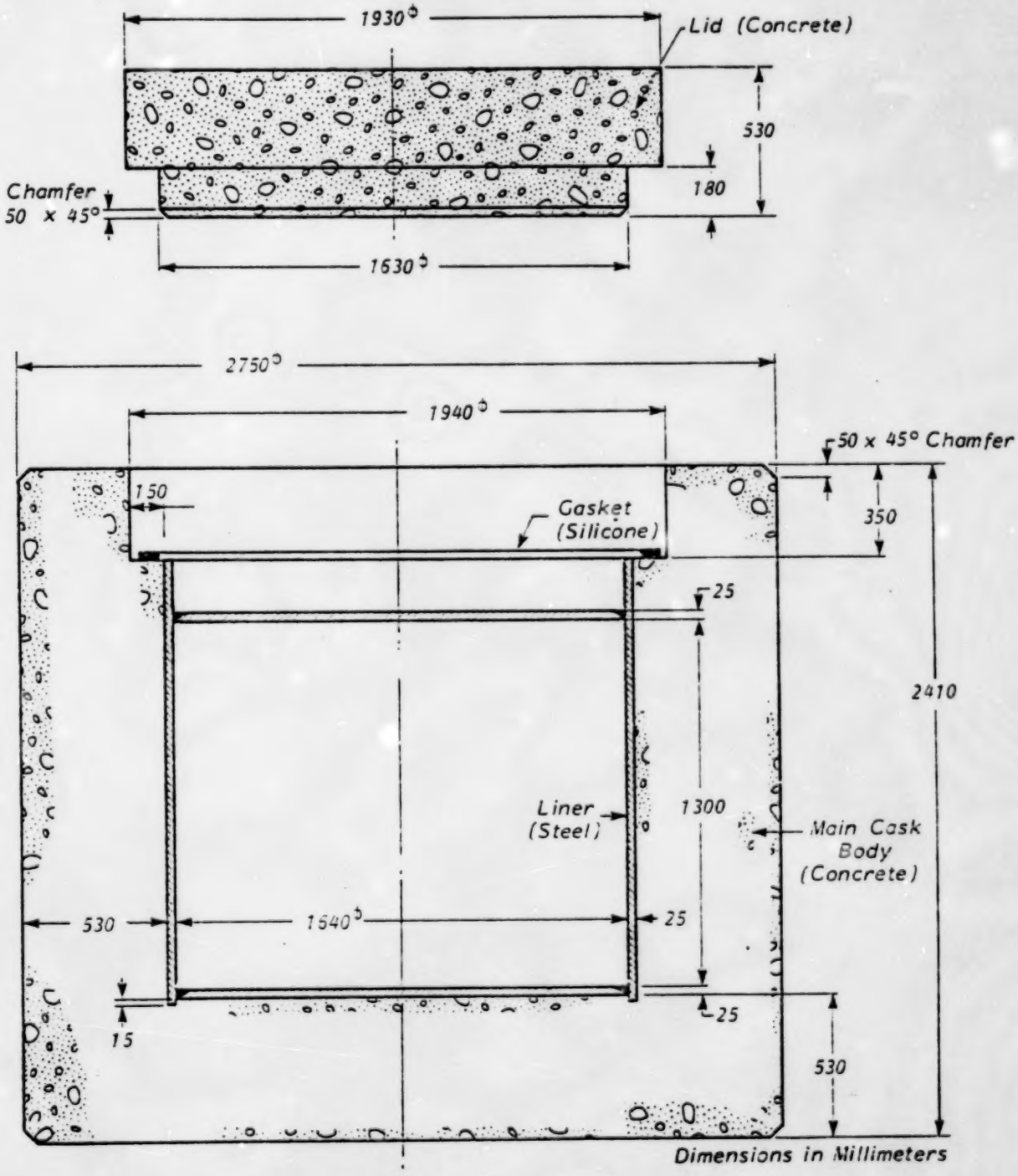

FIGURE 1

CONCRETE CASK
SECTION (SCALE 1:20)

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APPENDIX B

PRELIMINARY COST ESTIMATE FOR CONCRETE CASK TEST PROGRAM

Preliminary Cost Estimate for Concrete Cask Test Program

Note: All estimated costs shown are based on:

(1) One half-scale test specimen;
(2) Engineer time @ $55/hr and technician time @ $45/hr.

1. Construction of 1/2 Scale Cask Specimen

(At OH Kipling Complex)

Activity	Eng Time (M.H.)	Tech Time (M.H.)	M&E (K$)	Sub-Total (K$)
Concrete materials and labour 1.5 m^3			9.7	9.7
Steel Liner (materials and labour) 500 kg				
Subtotal			9.7	9.7
10% Contingency				1.0
Total				10.7

Preliminary Cost Estimate for Concrete Cask Test Program

2. Decay Heat Test (at OH Kipling Complex)

Activity	Eng Time (M.H.)	Tech Time (M.H.)	M&E (K$)	Sub-Total (K$)
1. Design instrumentation (for strain and temperature measurements)	40			2.2
2. Purchase instruments	40		20.0	22.2
3. Install instruments in specimen	15	100	3.0	8.0
4. Develop data acquisition software	70			3.9
5. Test set-up and instrument hook-up	40	40	2.0	5.9
6. Perform test (temperature cycling and instrument monitoring)	90	90	1.0	9.7
7. Analyze data	100			5.5
8. Prepare test report	120	20	0.5	7.9
Subtotal	515	250	26.5	65.3
10% Contingency				6.5
Total				71.8

Preliminary Cost Estimate for Concrete Cask Test Program

3. Drop Tests I and II (at OH Kipling Complex) and Fire Test (at U.L.C.)

Activity	Eng Time (M.H.)	Tech Time (M.H.)	M&E (K$)	Sub-Total (K$)
1. Design drop target (concrete block lined with steel plate on top)	50	50		4.9
2. Construct drop target				
Excavation				
130 m^3				
Concrete (materials and labour)	20		45.0	46.1
27 m^3				
Steel (materials and labour)				
3000 kg				
3. Design instrumentation (for acceleration, strain and temperature measurements)	40			2.2
4. Purchase instruments and recording device	40		20.0	22.2
5. Install instruments in test specimen	20	100	4.0	9.3
6. Develop data acquisition software for furnace test	70			3.9
7. Drop test set-up and instrument hook-up	50	50	4.0	8.9
8. Perform drop tests I and II	35	35	2.0	5.4
9. Fabricate steel support for furnace test	15	80	2.0	6.2
10. Transport specimen to ULC for furnace test	10	20	1.5	2.9
11. Furnace test set-up and instrument hook-up	50	50	3.0	7.9
12. Perform furnace test	25	25	1.0	3.4
13. Services rendered by ULC			6.0	6.0
14. Analyze test data	100			5.5
15. Prepare test report	150	20	0.5	9.6
Subtotal	675	430	89.0	144.4
10% Contingency				14.4
Total				158.8

Preliminary Cost Estimate for Concrete Cask Test Program

4. Drop Tests I and II and Fire Test (at CRNL)

Activity	Eng Time (M.H.)	Tech Time (M.H.)	M&E (K$)	Sub-Total (K$)
1. Design instrumentation (for acceleration, strain and temperature measurements)	40			2.2
2. Purchase instruments and recording device	40		20.0	22.2
3. Install instruments in test specimen	20	100	4.0	9.3
4. Fabricate steel support for open-fire test	15	80	2.0	6.2
5. Develop data acquisition software for open-fire test	70			3.9
6. Transport specimen to Chalk River, Ont	10	20	3.0	4.4
7. Drop test set-up and instrument hook-up	50	50	4.0	8.9
8. Perform drop tests I and II	35	35	2.0	5.4
9. Open-fire test set-up and instrument hook-up	50	50	3.0	7.9
10. Perform fire test	25	25	2.0	4.4
11. Services rendened by AECL			5.0	5.0
12. Analyze test data	100			5.5
13. Prepare test report	150	20	0.5	9.6
Subtotal	605	380	45.5	94.7
10% Contingency				9.5
Total				104.2

Preliminary Cost Estimate for Concrete Cask Test Program

5. Water Immersion Test (at WNRE)

Activity	Eng Time (M.H.)	Tech Time (M.H.)	M&E (K$)	Sub-Total (K$)
1. Design instrumentation (for strain and pressure measurements)	40			2.2
2. Purchase instruments	40		12.0	14.2
3. Install instruments in specimen	20	100	3.0	8.3
4. Transport specimen to Pinawa, Manitoba	10	20	7.0	8.4
5. Develop data acquisition software	70			3.9
6. Test set-up and instrument hook-up	40	40	2.0	5.9
7. Perform water immersion test	25	25	1.0	3.4
8. Services rendered by AECL			5.0	5.0
9. Analyze data	80			4.4
10. Prepare test report	100	20	0.5	6.8
Subtotal	425	205	30.5	62.5
10% Contingency				6.3
Total				68.8